



Generation of many-body Bell correlated states in optical lattices

Researchers from ICFO, University of Warsaw and Institute of Physics, Polish Academy of Sciences show how to generate many-body Bell correlated states using ultracold quantum gases in optical lattices

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Quantum correlations are a fundamental aspect of quantum mechanics. They refer to the correlations between the outcomes of measurements performed on two or more particles in a quantum system. These correlations can exhibit strange and counterintuitive behaviors not present in classical systems.

The phenomenon of entanglement is an example of quantum correlations. It describes the correlation between two or more particles, a property that classical physics cannot explain. For example, if two particles are entangled, the outcome of the measurement performed on one particle can be used to predict the state of the other, even if the particles are separated by large distances. Bell correlations are another example, and they refer to correlations between the outcomes of measurements performed on two or more particles that any local

hidden variable theory cannot explain. These correlations are often used to demonstrate the non-classical nature of quantum mechanics and the limitations of classical theories. Now, quantum correlations are a key element in developing quantum technologies exploiting the unique properties of quantum systems to perform tasks that are not possible using classical technologies, including quantum teleportation, quantum cryptography, and quantum computing. However, the generation of many-body Bell correlated states, especially those implemented during the One-Axis Twisting protocol (OAT) procedure, was still an open question so far for science until now. In an international study published in Physical Review Letters, ICFO researcher **Dr Marcin Płodzien** (also NAWA Bekker 2020 Fellow) and **ICREA Professor Maciej Lewenstein**, in collaboration with **Professor Jan Chwedenczuk** from the University of Warsaw and **Professor Emilia Witkowska** from the Institute of Physics, Polish Academy of Sciences, have shown that massively correlated quantum many-body states could be generated through current ultracold bosons in optical lattices experiments, using the One-Axis Twisting protocol (OAT) known for generating spin squeezed states.

Spin squeezing states

While entanglement shows how correlated particles can be, spin squeezing is a phenomenon that occurs in a system of particles with a shared quantum state, such as a group of atoms or ions. It involves decreasing as much as possible the uncertainty in the measurement of one of the observables, or $i\frac{1}{2}\text{spin}_i\frac{1}{2}$ variables, at the expense of increasing the uncertainty in the measurement of the other variables involved. One of the most well-known methods for generating squeezed entangled states is the one-axis twisting protocol (OAT). It can be implemented using various ultra-cold systems interacting through collisions or atom-light interactions and it was well understood that it creates many-body entangled states and two-body Bell correlations. But, in their work, the researchers showed that the one-axis twisting is also a viable resource for powerful many-body Bell correlations. They presented a systematic analytical study of creating many-body Bell-correlated states during one-axis twisting dynamics in two-component bosonic systems. They then provided the critical time at which the many-body Bell correlations emerge together with a simple yet powerful formula for characterizing the depth of the Bell correlations and entanglement. These findings were then applied to classify the generation of many-body Bell correlations in systems of two-component bosons loaded into a one-dimensional optical lattice. The results obtained in this study show that such correlations can be created with the present technology - this is very important from the point of view of potential applications as Bell correlations are known to boost the precision of quantum sensors or to improve the security of quantum cryptography protocols. The fundamental aspects of creating such ultra-non-classical many-body states are relevant, especially in light of the recent N

bel prize, which was awarded for the pioneering studies of such phenomena.